Reducing NASA Mission Risks Through Green Engineering

NASA TEERM Conference

Goddard Space Center

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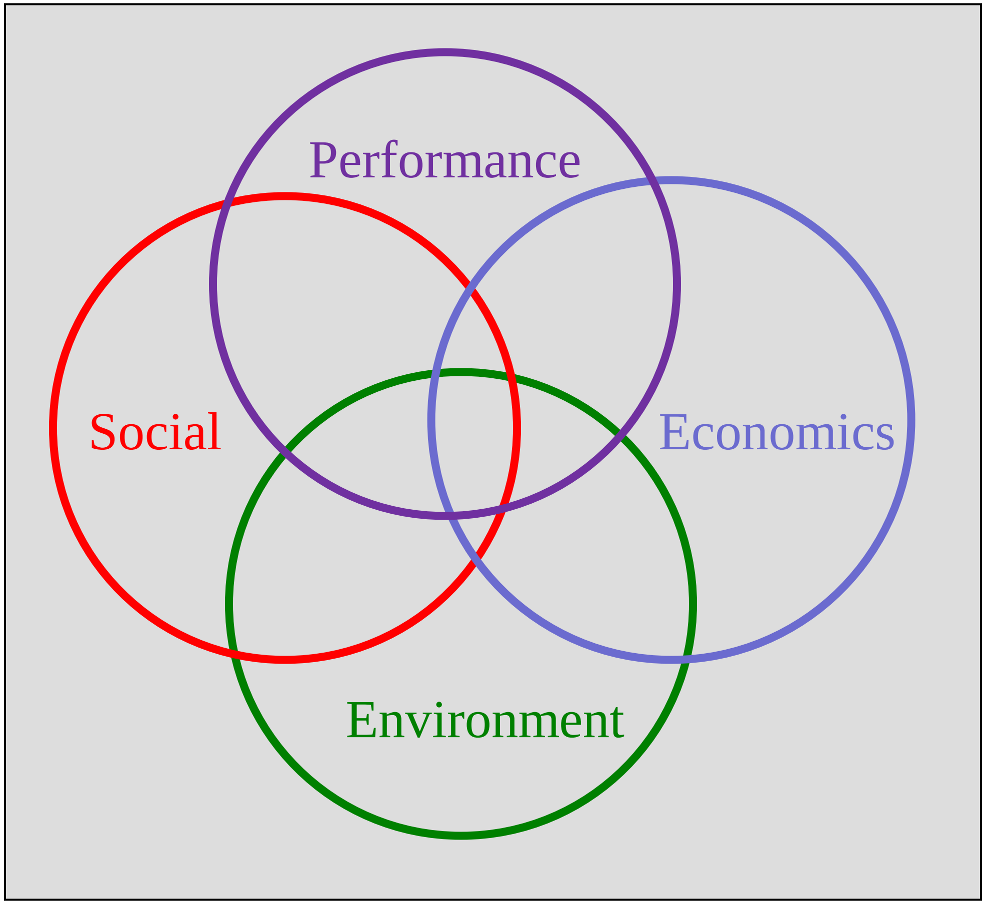
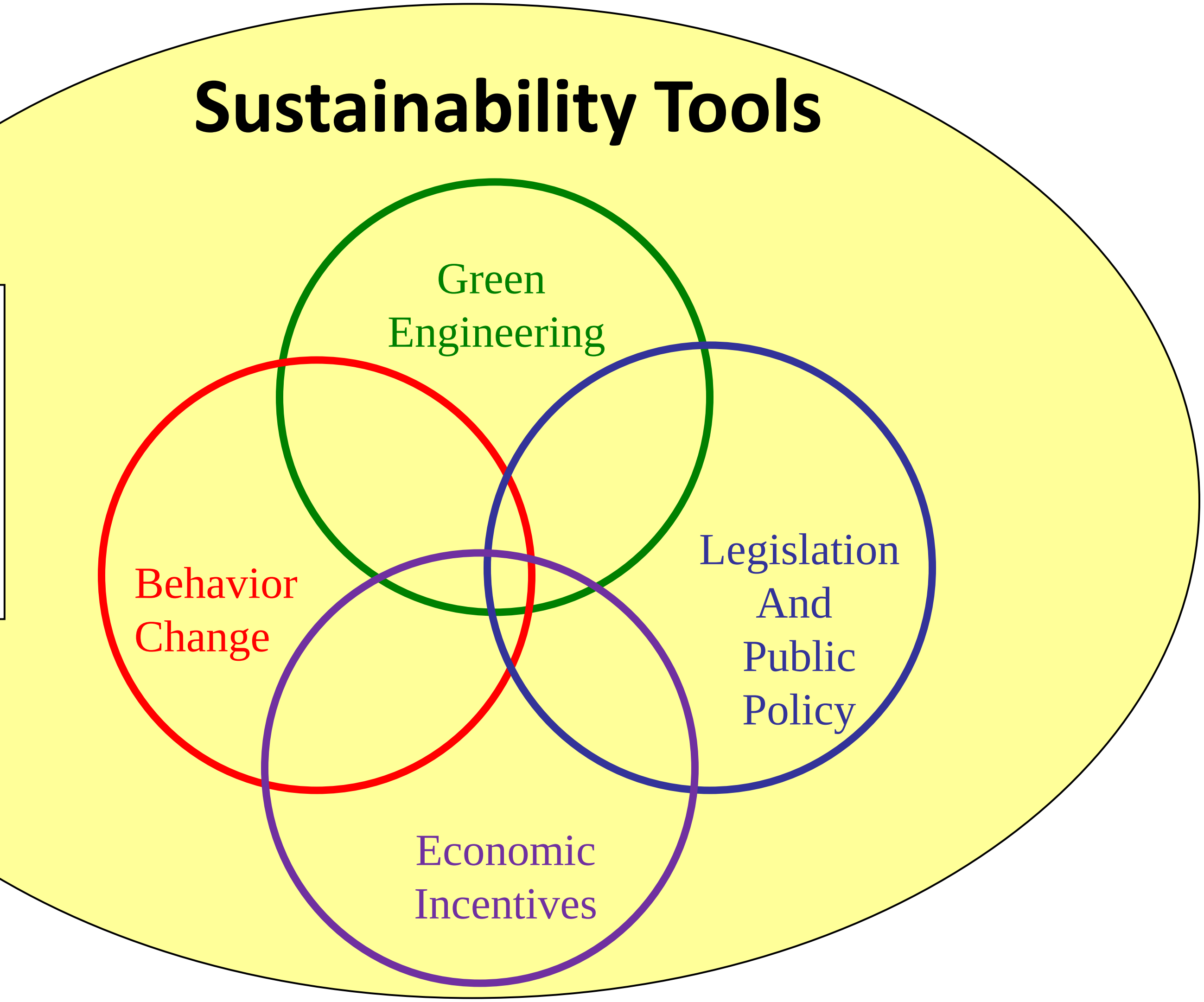
Sustainability & The Triple Bottom Line



- Sustainability is about difficult trade-offs today in attempts to improve quality of life in the future.
- Sustainability decisions depend critically on the time frame and stakeholders preferences.
- The Triple Bottom Line doesn't matter if the mission (performance) isn't achieved.

How Are Green Engineering And Sustainability Related?



Green Engineering Balances Design Parameters Including Environmental Impact

Technical Performance

Costs

Environmental Impact

- ***Life Cycle Analysis (LCA)***

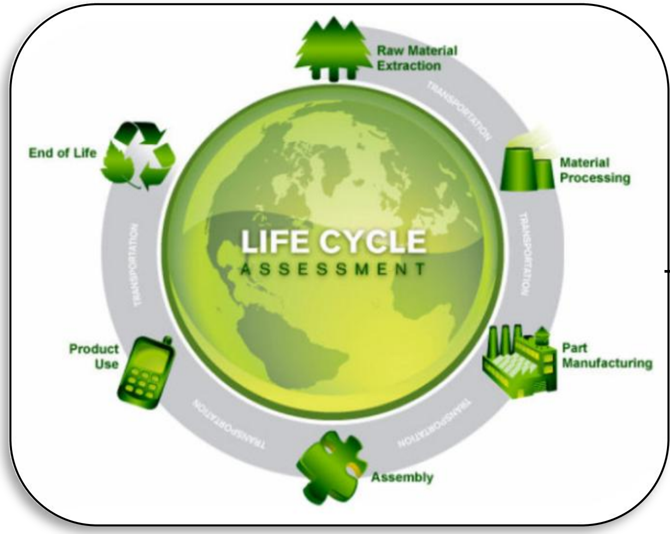
- Green Engineering considers environmental impacts as ***initial design constraints*** and attempts to minimize them across the entire life cycle while balancing the other requirements.

Schedule

Safety

Life Cycle Assessment (LCA) Is A Decision-Making Tool

Inputs
- *Materials*
- *Chemicals*
- *Energy*
- *Water*



www.solidworks.com/sustainability/design/2722_ENU_HTML.htm

Outputs
- *Products*
- *Solid Waste*
- *Liquid Waste*
- *Gaseous Waste*
- *Heat*

Characterization Factors

IMPACTS

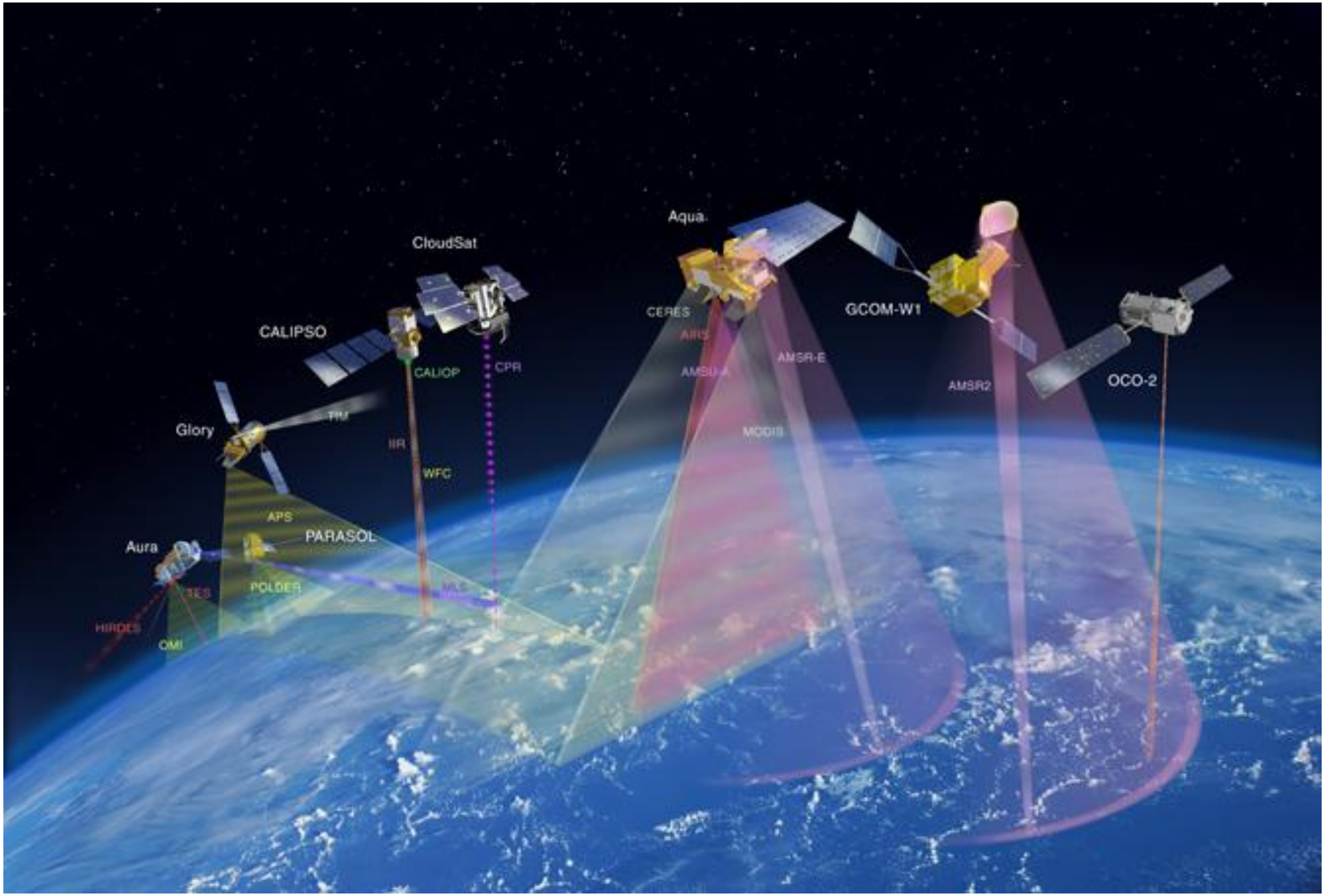
Atmosphere:
Climate Change
Ozone Depletion
Smog Formation
Acidification
Human Health

Hydrosphere:
Eutrophication
Acidification
Aquifer depletion
Ecotoxicity
Human Health

Biosphere:
Soil depletion
Deforestation
Resource Depletion
Ecotoxicity
Human Health

- LCA quantifies environmental impacts across all the entire life cycle on the product/process
- LCA helps to avoid shifting the environmental burden from one aspect of the system to another.

SpaceTechnology Provides Impact Characterization Factors Through Missions



http://www.nasa.gov/mission_pages/a-train/a-train.html

LCA Models Are Snapshots Which Balance Feasibility And Complexity

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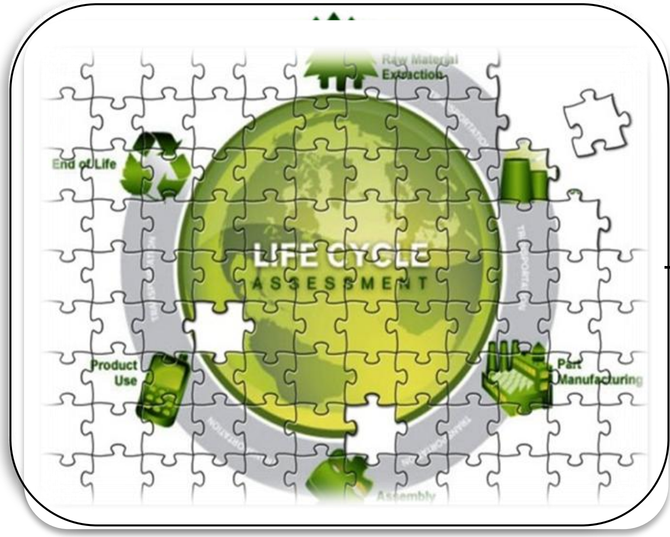
- *Chemicals*
- *Energy*
- *Water*



System Boundary

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- *Solid Waste*
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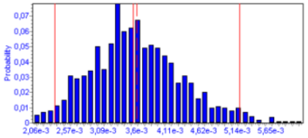
- In many cases, the results that emerge are clear enough for a decision even if some of the pieces of the model are missing

Sensitivity Analysis Can Probe The LCA Model



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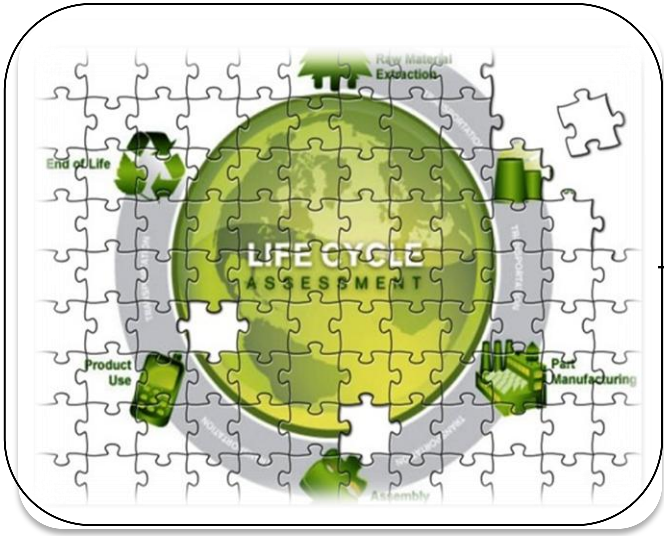

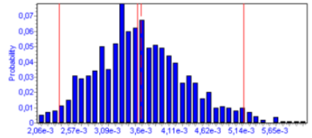

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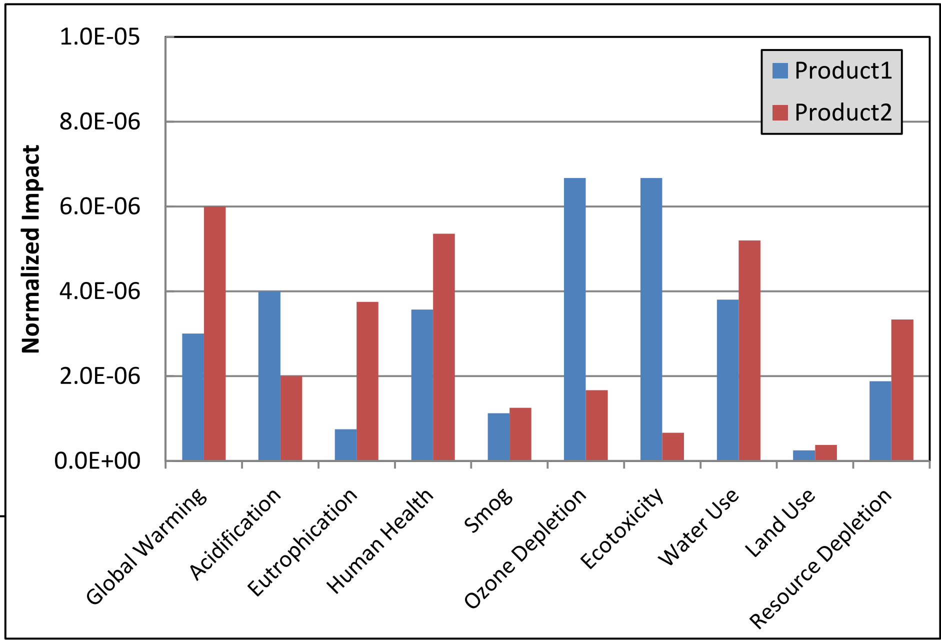

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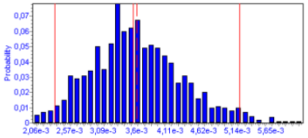

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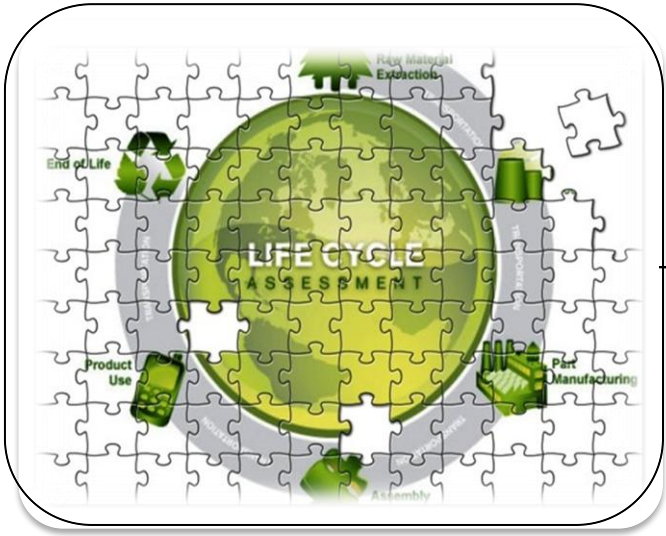

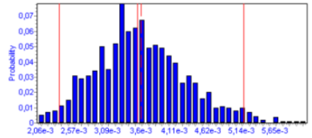

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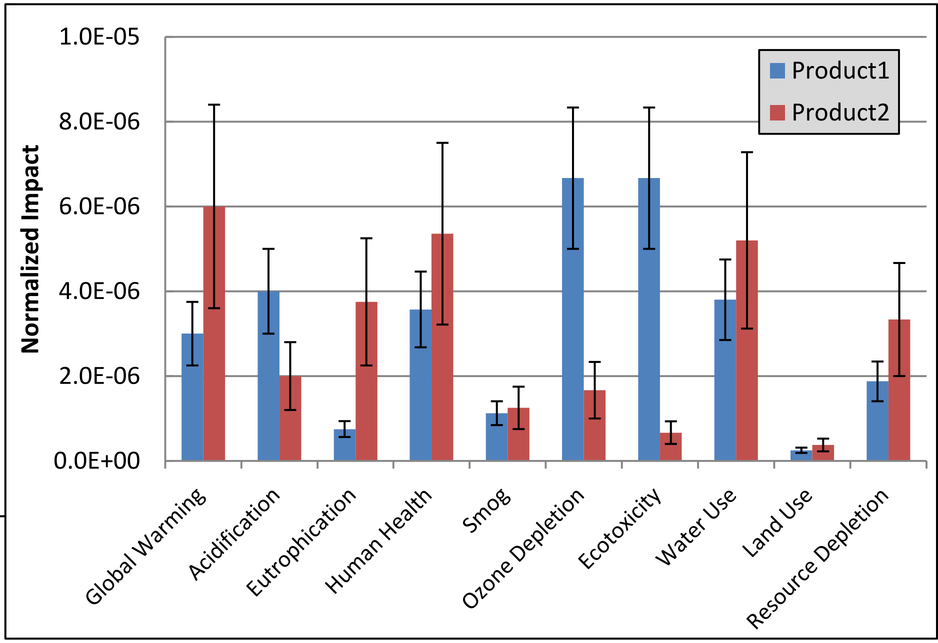

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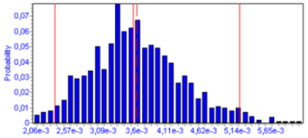

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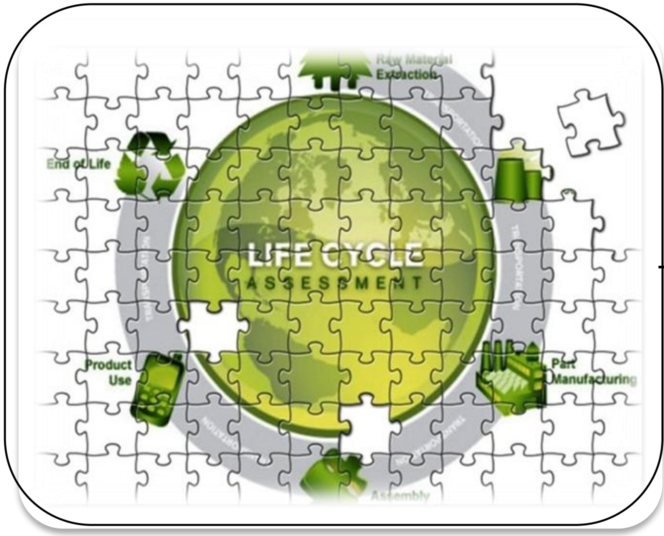

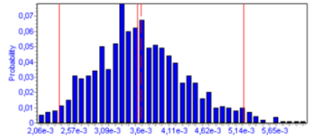

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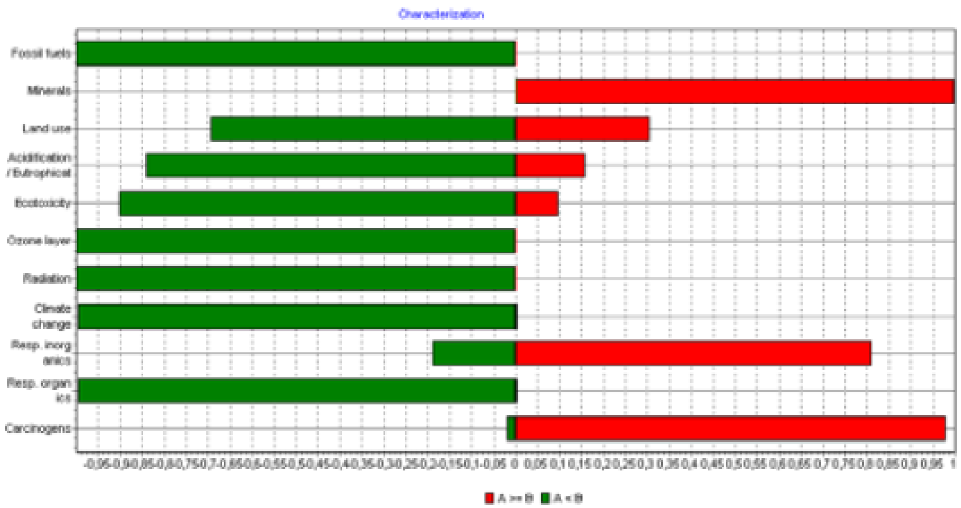


LCA Limitations For Decision-Making

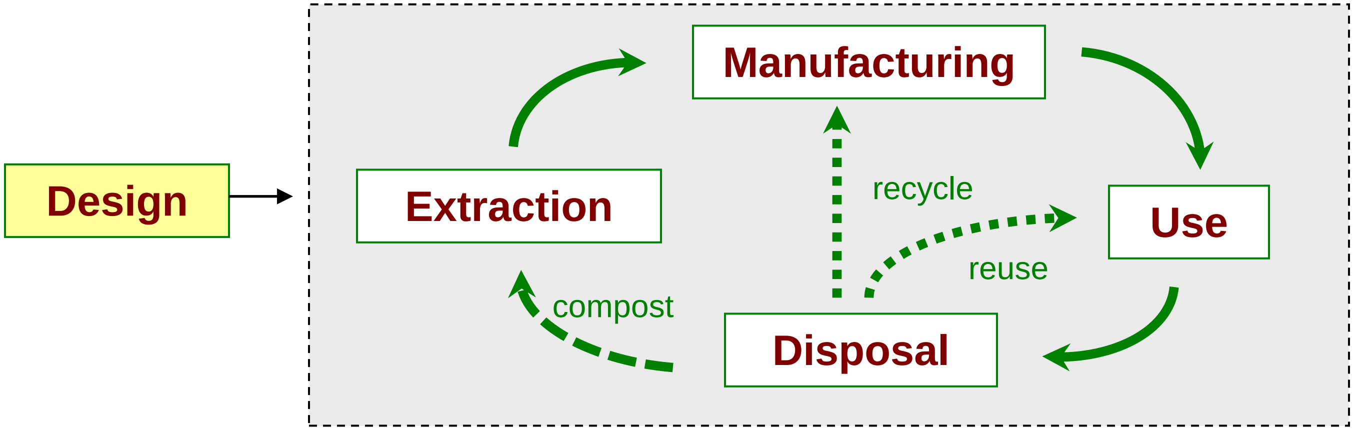
- *Barriers to LCA arise because many stakeholders want a final answer, to be "cleared for take off, with no call-backs." These stakeholders see LCA as a final exam; pass it and you are done being concerned with impacts and can proceed to technology deployment.*

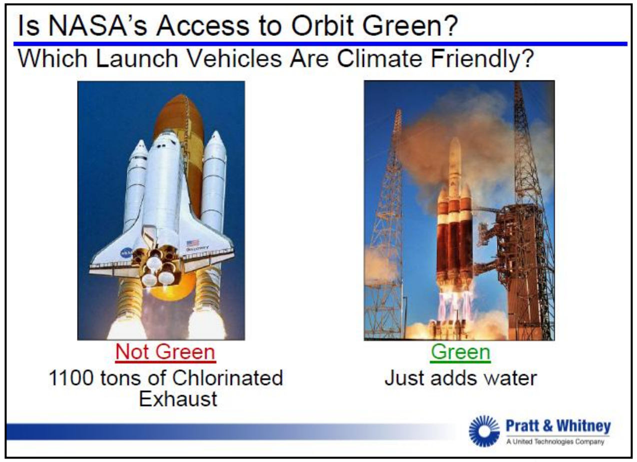
- *At its best, LCA contributes to an ongoing process that organizes both information and the process of prioritizing information needs. We do not see these grand challenges as hurdles to be cleared, but rather as opportunities for the practitioner to focus attention and effort on making LCA more useful to decision makers.*

- *Decision makers who work in real time and often cannot wait for precise results must recognize that LCA can provide valuable insight but it is not necessarily a "truth-generating machine". Effective LCA can guide and inform decisions, but it cannot replace the wisdom, balance, and responsibility exhibited by effective decision-makers.*

T. McKone, et al., Grand Challenges for Life-Cycle Assessment of Biofuels, Environmental Science & Technology, 45 (5), pp 1751–1756, 2011.

Life Cycle (Systems) Thinking vs. LCA

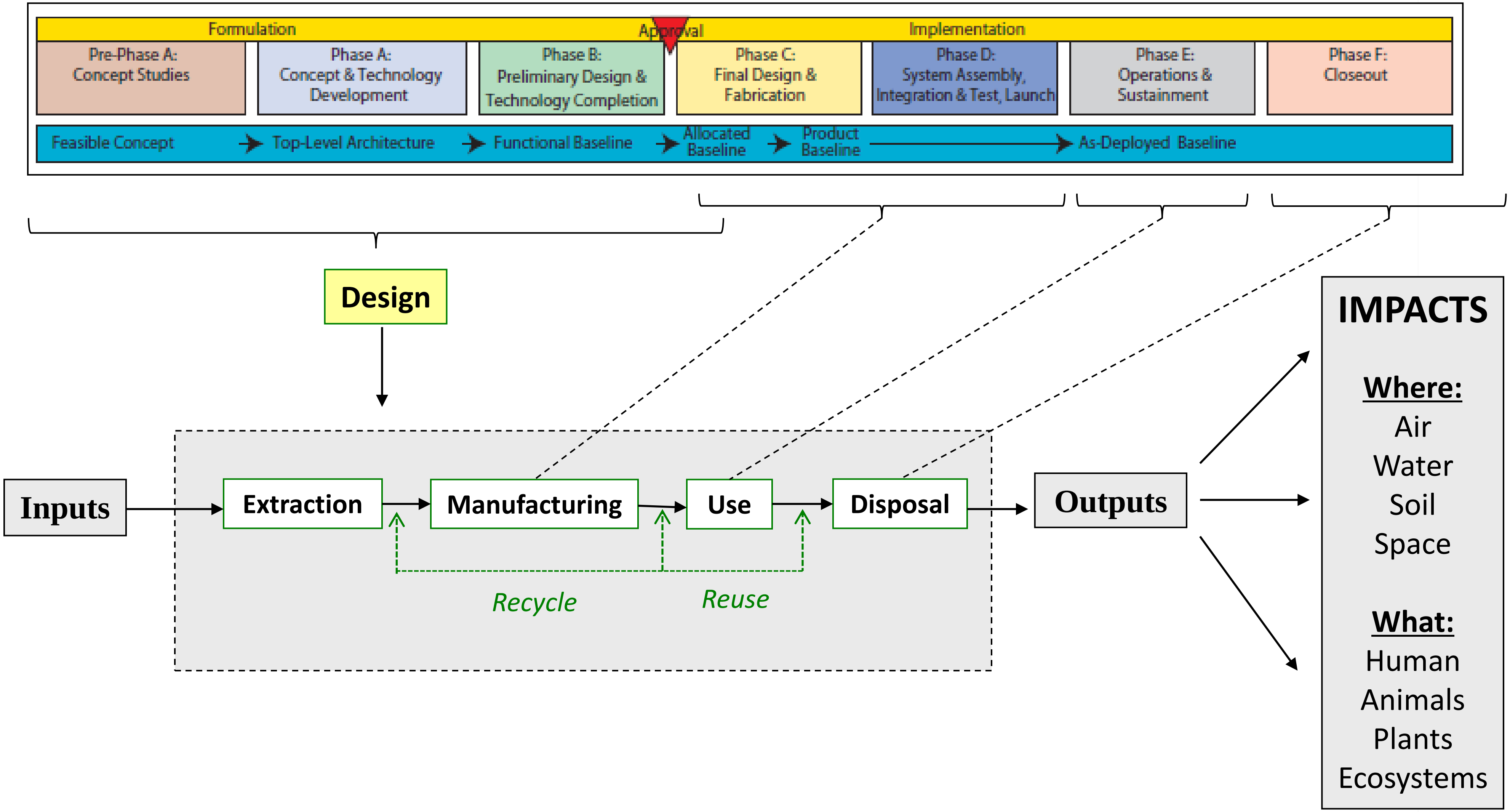




www.nasa.gov/centers/kennedy/news/propnorthopens.html

NASA's Green Global Challenge, Alan Epstein, Pratt & Whitney, NASA Green Engineering Master's Forum, Sept. 2009.

Mission Life Cycle Environmental Considerations



NASA's Major Risks to Supporting Mission

- **Green engineering is world-class engineering, providing quantitative analysis to balance competing factors and mitigate uncertain environmental risks.**

1) Aging infrastructure
2) Increasing energy cost
3) Greenhouse gas management
4) Climate change impacts and adaptation
5) Changing laws and requirements
6) Mandates without added resources
7) Environmental cleanup – Apollo Era
8) Material availability and obsolescence
9) Encroachment – neighbors need water, energy, safety, resources

Mission Risks:

- *Not enough money*
- *Not enough time*
- *Materials availability*
- *Environmental Damage*
- *Human Health Problems*
- *Poor communication*

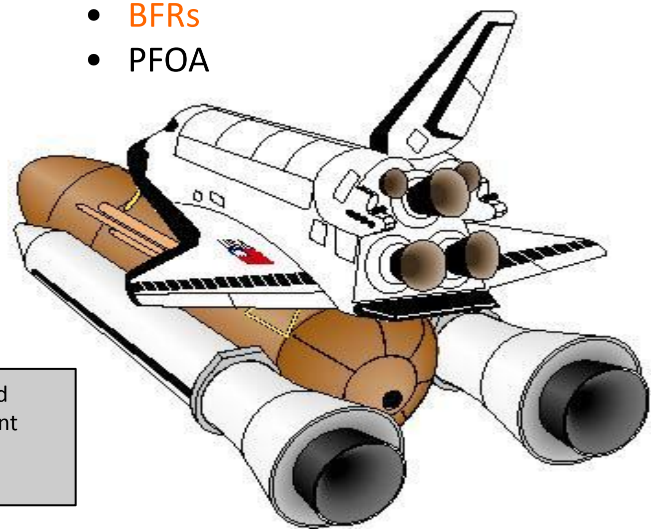
Risk Example - Environmental and Health Issues Associated with Chemical Inputs/Outputs

External Tank
- HCFC-141b
- Cadmium
- Hexavalent Chromium
- High VOC coatings
- Cleaning/verification solvents
- Methyl ethyl ketone
- BFRs
- PFOA

Reusable Solid Rocket Motors
- HCFC 141b
- Trichloroethane
- Cadmium
- Hexavalent Chromium
- High VOC Coatings
- Hypalon
- Lead-free electronics
- BFRs
- PFOA

Orbiter
- HCFC-141b
- Trichloroethane
- Cadmium
- Hexavalent Chromium
- Methyl Ethyl Ketone
- High VOC coatings
- Lead-free electronics
- Hazardous Air Pollutant Inks
- Cleaning/verification solvents
- Methyl ethyl ketone
- PFAS
- BFRs
- PFOA

VOC = Volatile Organic Compound
BFR = Brominated Flame Retardant
PFOA = Perfluorooctanoic Acid
PFAS = Perfluoroalkyl Sulfonates



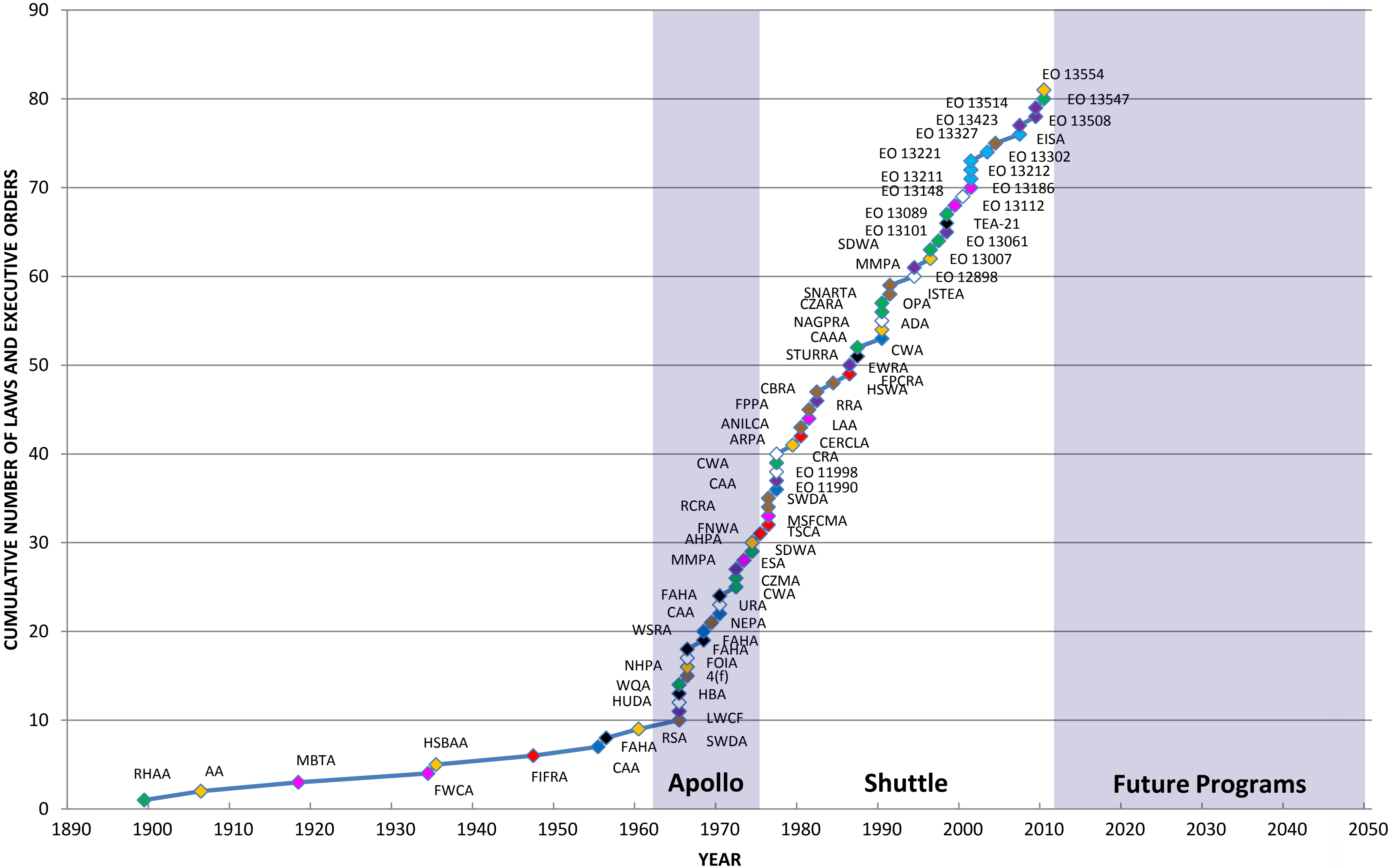
Space Shuttle Main Engines
- Hexavalent Chromium
- Cadmium
- Lead-free electronics
- Cleaning/verification solvents
- PFOA

Solid Rocket Boosters
- HCFC-141b blowing agent
- Hexavalent Chromium
- Lube-Lok
- High VOC Coatings
- Hypalon paint
- Lead-free electronics
- BFRs
- PFOA

Flight Crew Equipment/EVA
- Hexavalent Chromium
- Lead-free electronics
- BFRs
- PFOA

C. Griffin, NASA KSC Engineering Directorate Evaluating Technologies to Mitigate Environmentally-Driven Risk to Mission, APPEL Green Engineering Course, May 26, 2012.

Evolution of Environmental Requirements



Air
Multiple
Chemical Management
Natural/Cultural Resources
Endangered Species
Other (White Points)
Energy
Transportation
Land/Waste
Water

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Risk Example – Remediation Costs

- In 2009, NASA estimated the cost of the agency's environmental liability, including cleanup costs, was $922 million.[1]

Plans for FY 2011

Environmental Compliance and Restoration

The FY 2011 funding request represents a prioritized, risk-based approach for addressing a total of 136 cleanup projects remaining at all NASA centers and is based upon the relative urgency and the potential health and safety hazards related to each individual cleanup. As studies, assessments, investigations, plans, regulatory approvals, and designs progress and as new discoveries or regulatory requirements change, it is expected that program priorities may change requiring revisions to planned activities. Major cleanups with the highest priority requirements planned for accomplishment in FY 2011 include the following:
1) Continue decommissioning and demolition of NASA's Plum Brook Reactor Facility. FY 2011 funding should allow NASA to terminate its Nuclear Regulatory Commission (NRC) license.
2) Address ground water and drinking water issues associated with contamination emanating from NASA's Jet Propulsion Laboratory;
3) Continue cleanup of ground water contamination at White Sands Test Facility; and
4) Accelerate cleanup of contamination at Santa Susana Field Laboratory to facilitate property transfer.

[1]http://www.spacenews.com/civil/091104-nasa-still-struggles-with-accounting.html
http://www.nasa.gov/news/budget/index.html

Risk Example – Remediation Costs

The purpose of NASA's Environmental Compliance and Restoration (ECR) program is to clean up chemicals released to the environment from past activities. Cleanups are prioritized to ensure that the highest priority liabilities are addressed first in order to protect human health and the environment and preserve natural resources for future missions.

FY 2011 Budget Request

Budget Authority ($ millions)	FY 2009 Actual	FY 2010 Enacted	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015
FY 2011 President's Budget Request	**0.0**	**448.3**	**397.3**	**363.8**	**366.9**	**393.5**	**398.5**
Construction of Facilities	0.0	381.1	335.2	316.3	319.5	344.6	349.0
Environmental Compliance and Restoration	0.0	67.2	62.1	47.5	47.4	48.9	49.5
Total Change from FY 2010 President's Budget Request	**0.0**	**448.3**	**397.3**	**363.8**	**366.9**	**393.5**	--

Note: In all budget tables, the FY 2011 President's Budget Request depicts the July 2009 Operating Plan including American Recovery and Reinvestment Act for the FY 2009 Actual column and the Consolidated Appropriations Act, 2010 (P.L. 111-117) without the Administrative transfers for the FY 2010 enacted column.

- Addition costs reside in individual programs and projects to deal with environmental regulations.

http://www.nasa.gov/news/budget/index.html

Process Improvement – Shuttle TCE Reduction

- The external tank for the NASA Space Shuttle used trichloroethylene (TCE) extensively in cleaning, degreasing, and liquid oxygen (LO2) verification processes.

- Trichloroethylene (TCE) is a Class II Toxic Air Pollutant and both a suspected carcinogen and reproductive toxin with a Threshold Limit Value (TLV) of only 100 ppm.

- This chemical comprised over 80% of the total emissions at the Michoud, Louisiana facility and was also subject to impending usage reductions under the Louisiana Air Toxics Regulations.

- Manned Space Systems reported TCE releases of 112,900 pounds for the 1988 Toxic Release Inventory (TRI) reporting year. (*2011 TRI preliminary data indicates 4.1 billion pounds or releases covering 513 chemicals from 20,927 facilities)*

http://www.zerowastenetwork.org/success/story.cfm?StoryID=284&RegionalCenter=
http://www.bna.com/epas-preliminary-tri-n17179870745/

Process Improvement – Shuttle TCE Reduction

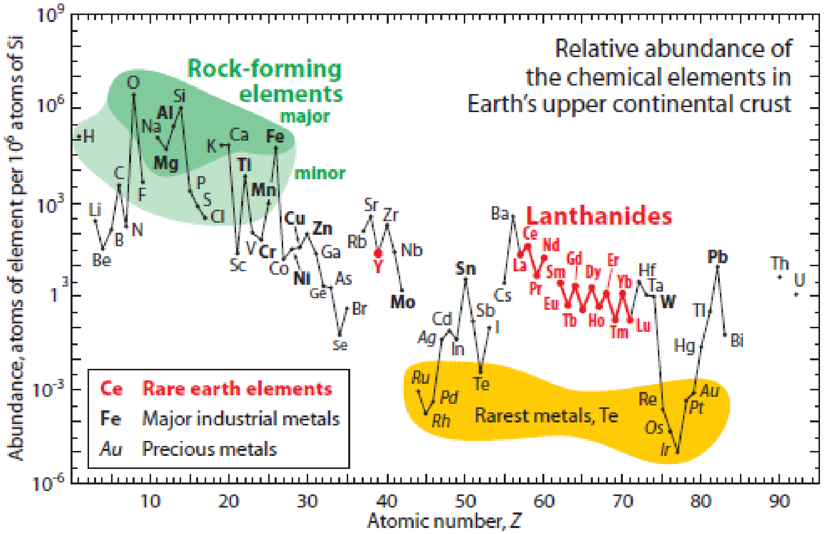
- **Process Optimization:**
  1. *Eliminating a step in the pre-cleaning of the LO2 tank.*
  2. *Modification of the process used to verify the cleanliness of the LO2 tank after final cleaning led to reduction from 5000 gallons to 5 gallons per validation sequence.*
  3. *Use of TCE in degreasing aluminum parts and panels was eliminated by reducing the amount of heavy oils on the parts and validating an alkaline cleaning step as a substitute for the TCE.*

- In 1991, TCE emissions were reduced to 100,400 pounds with air emissions at 55,000 pounds.
- By 1995, air emissions were down to less than 4,000 pounds and overall releases below the 10,000 pound TRI reporting threshold.
- A site that once required 16,000 gallon product storage capacity has reduced usage to five gallon increments.

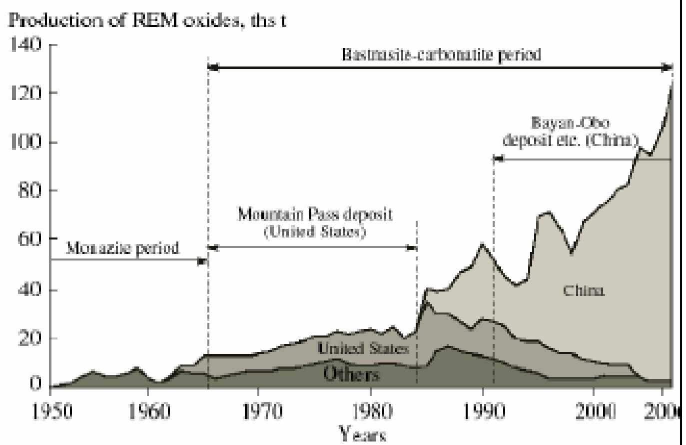
- **Triple Bottom Line benefits:**
  – Reduced potential employee exposure through use and accidents, Elimination of bulk storage requirements, Reduced reporting, Reduced chemical costs

http://www.zerowastenetwork.org/success/story.cfm?StoryID=284&RegionalCenter=

Extraction and Use of Rare Earth Metals



97% of primary production of rare earth metals (Sc + Y + lanthanoids) comes from China



Sources: naumov 2008, Fraunhofer Institute 2009

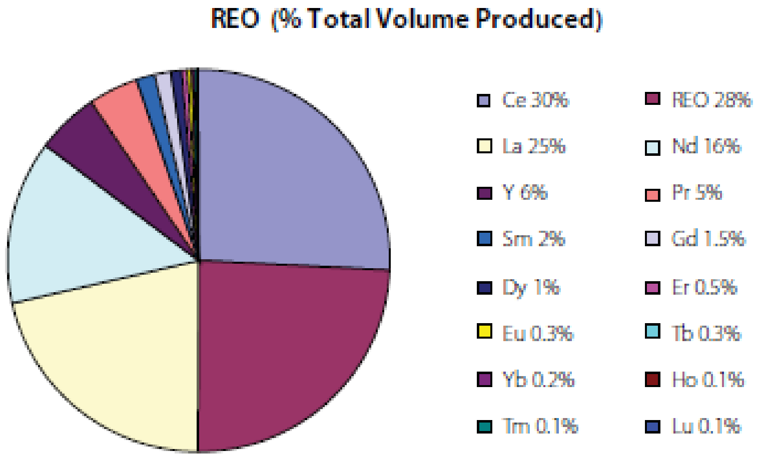


Figure 2. Distribution of rare earths by percentage of total volume produced. REO reflects mixed metal rare earth oxides.

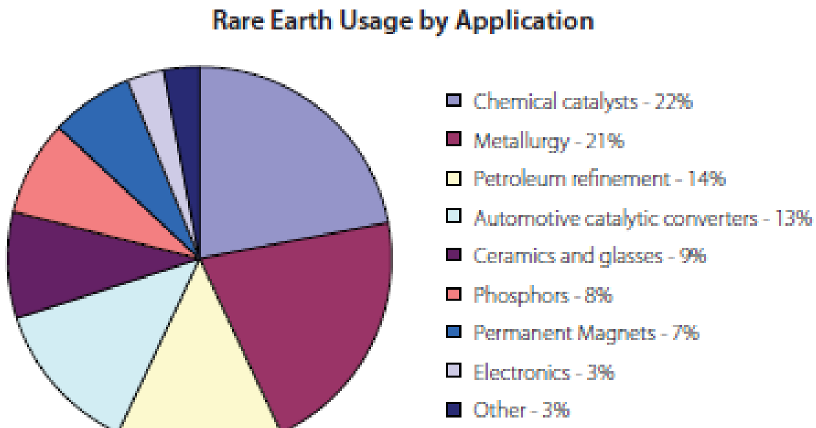
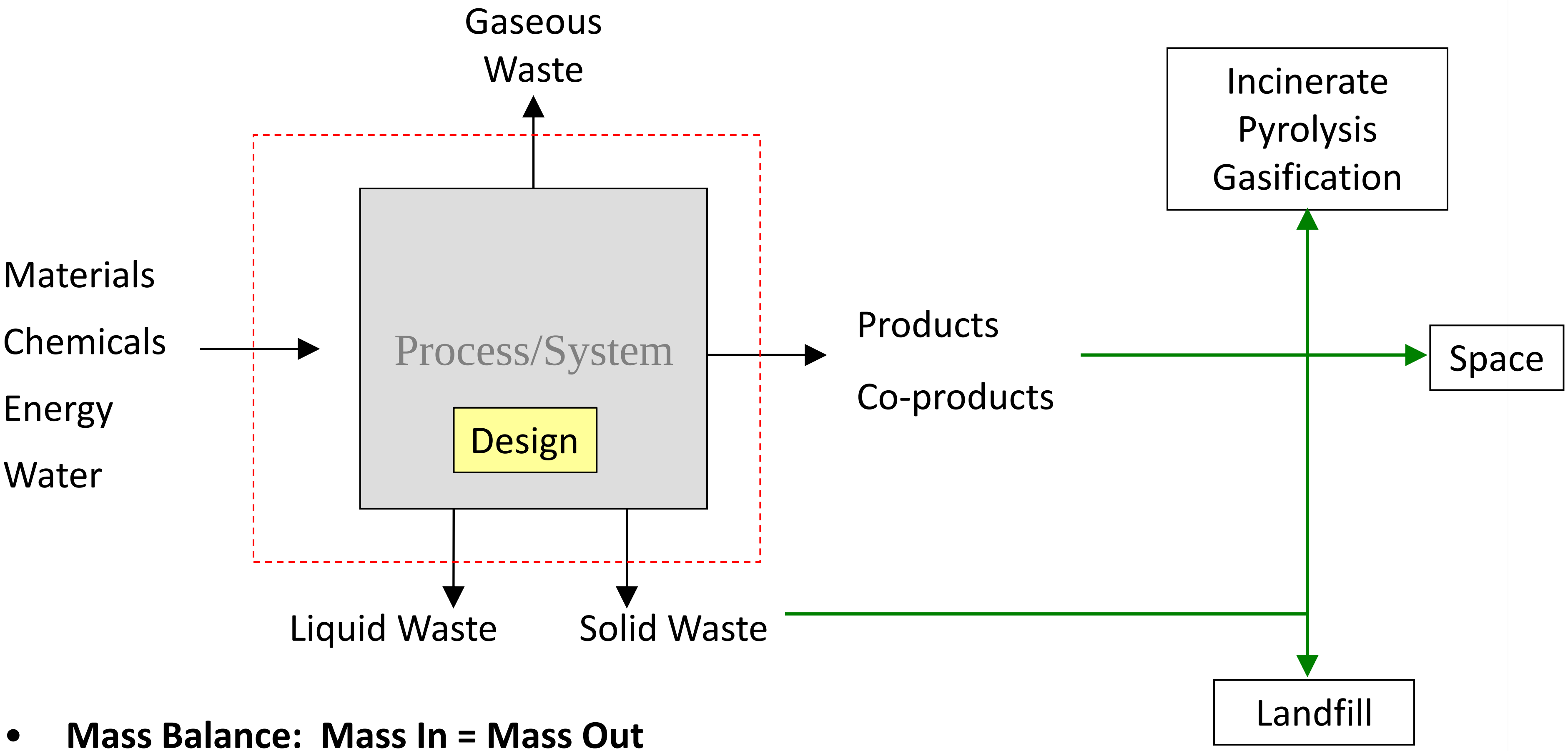


Figure 3. End use distribution of rare earth elements by application in 2009. Data from USGS Mineral Commodity Summaries.

http//www.sigmaaldrich.com/materials-science/learning-center/material-matters.html
Materials Matters, volume 6, number 2, pp. 32 – 33, June 2011.

Green Engineering Considers Waste As Design Flaw



- **Mass Balance: Mass In = Mass Out**
- **Waste = Materials = Money = Energy = Food *("Cradle to Cradle")***
- **Upstream changes (design) have biggest opportunity for benefits**

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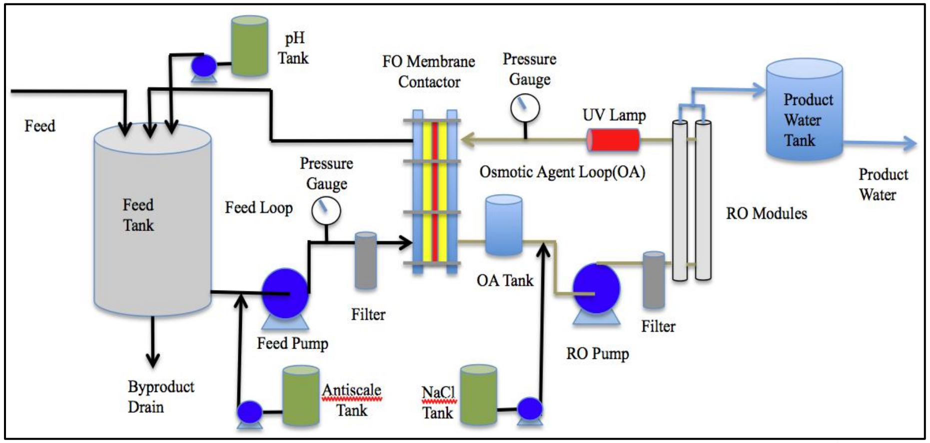
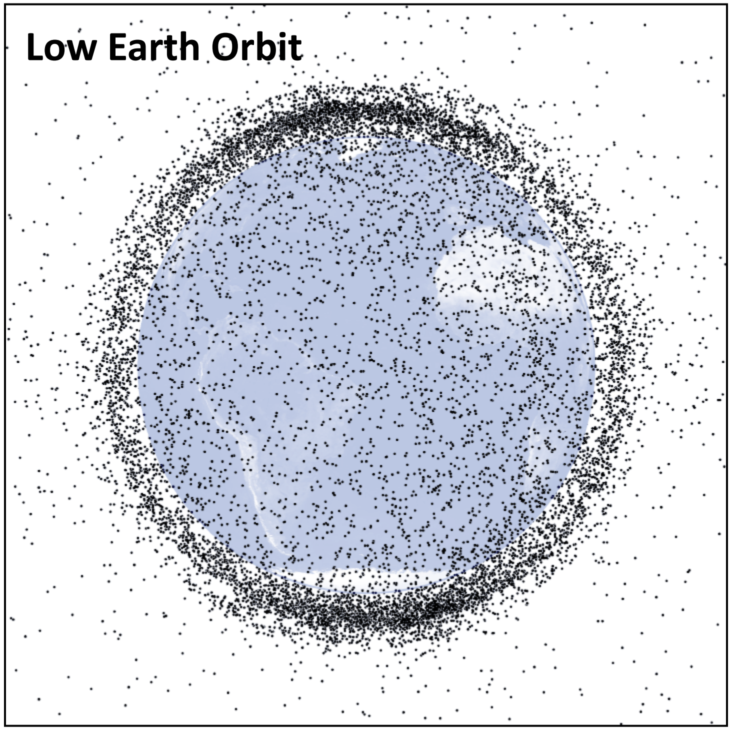
Water Purification (Biomimicry Example)

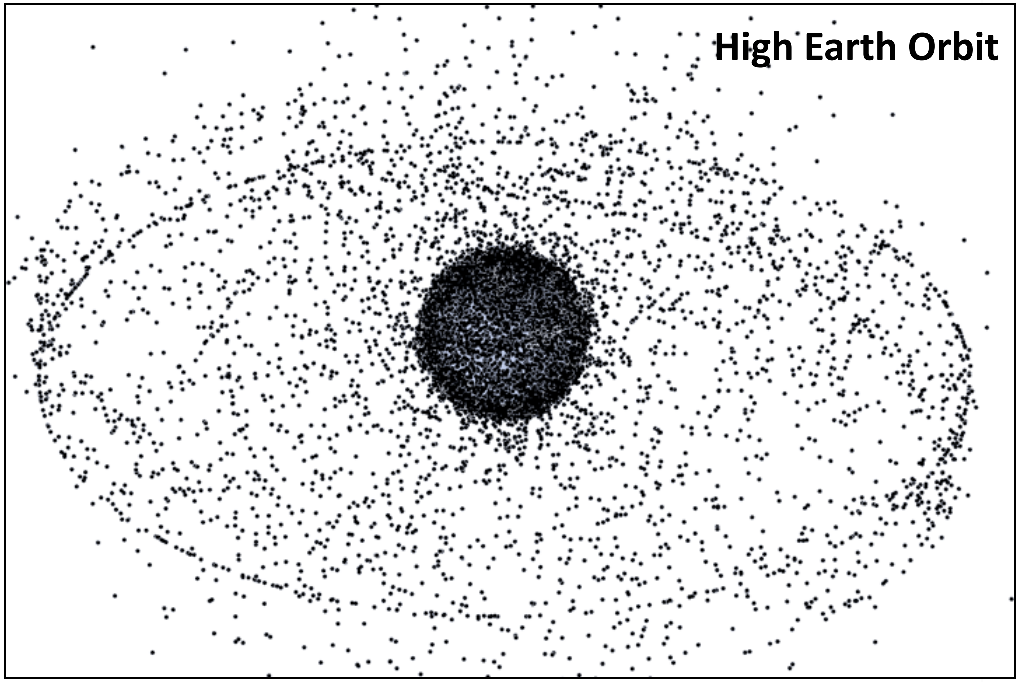
Sustainability Base – NASA Ames Graywater Treatment System:

- Forward Osmosis (FO) works like the small intestine in the body to transfer water out of the waste stream and into the body to the blood.
- Osmotic potential between two fluids of differing solute/solvent concentrations equalize by the movement of solvent from the less concentrated solution to the more concentrated solution.
- Reverse osmosis (RO) is then used to produce purified water and concentrated solution used in forward osmosis. You can't just use RO for treatment in this case due to solids and surfactants in the graywater.



Risks from Disposal - Space Debris

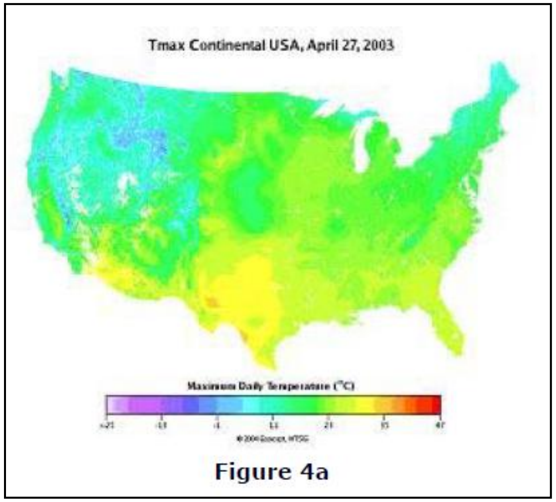


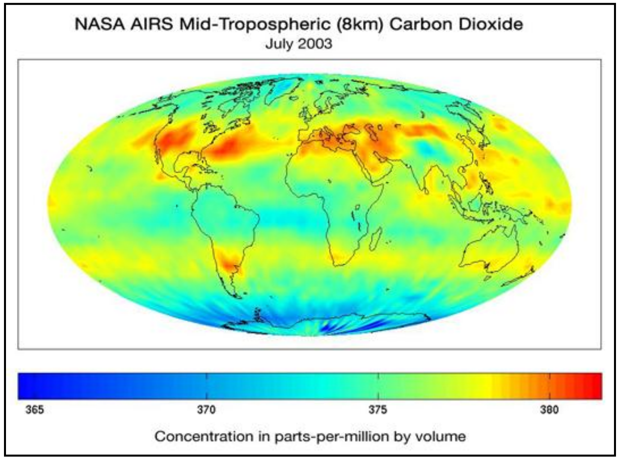


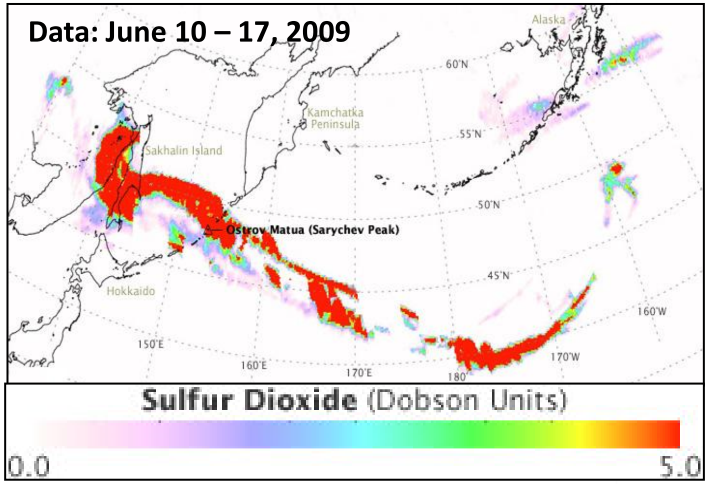
- As of July 2009, approximately 19,000 objects larger than 10 centimeters are tracked in Earth orbit by the US Space Surveillance Network.
- ***Design for Demise*** methodologies consider this issue on the front end of the mission

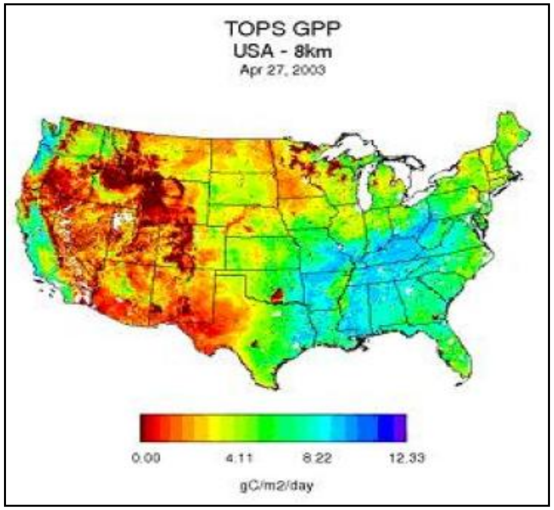
http://earthobservatory.nasa.gov/IOTD/view.php?id=40173

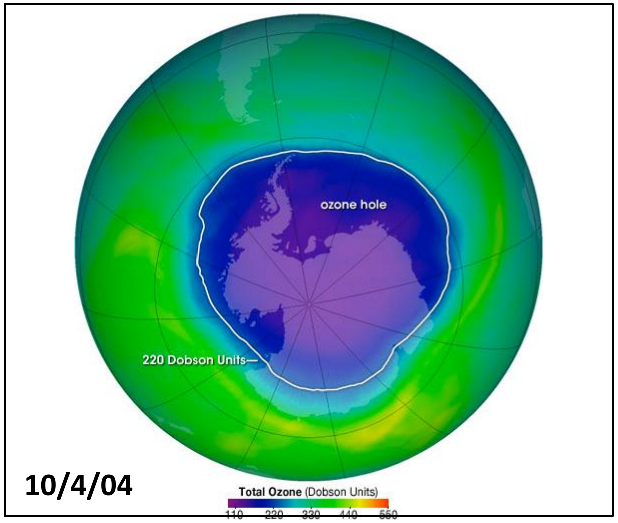
Green Engineering Projects Provide Communication Opportunities

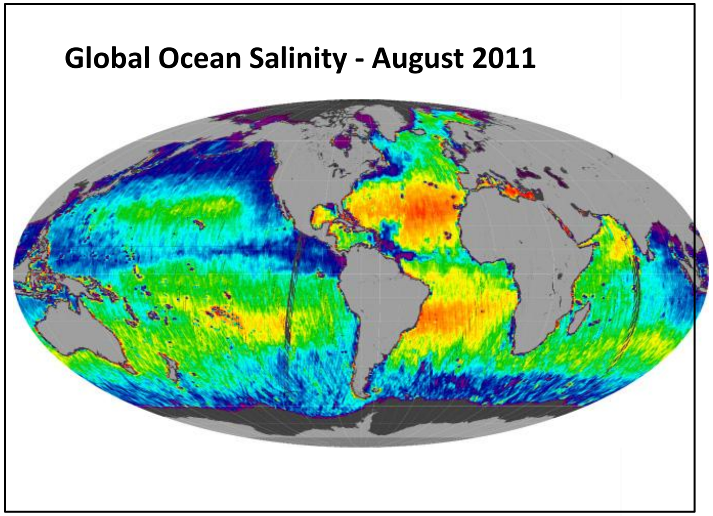




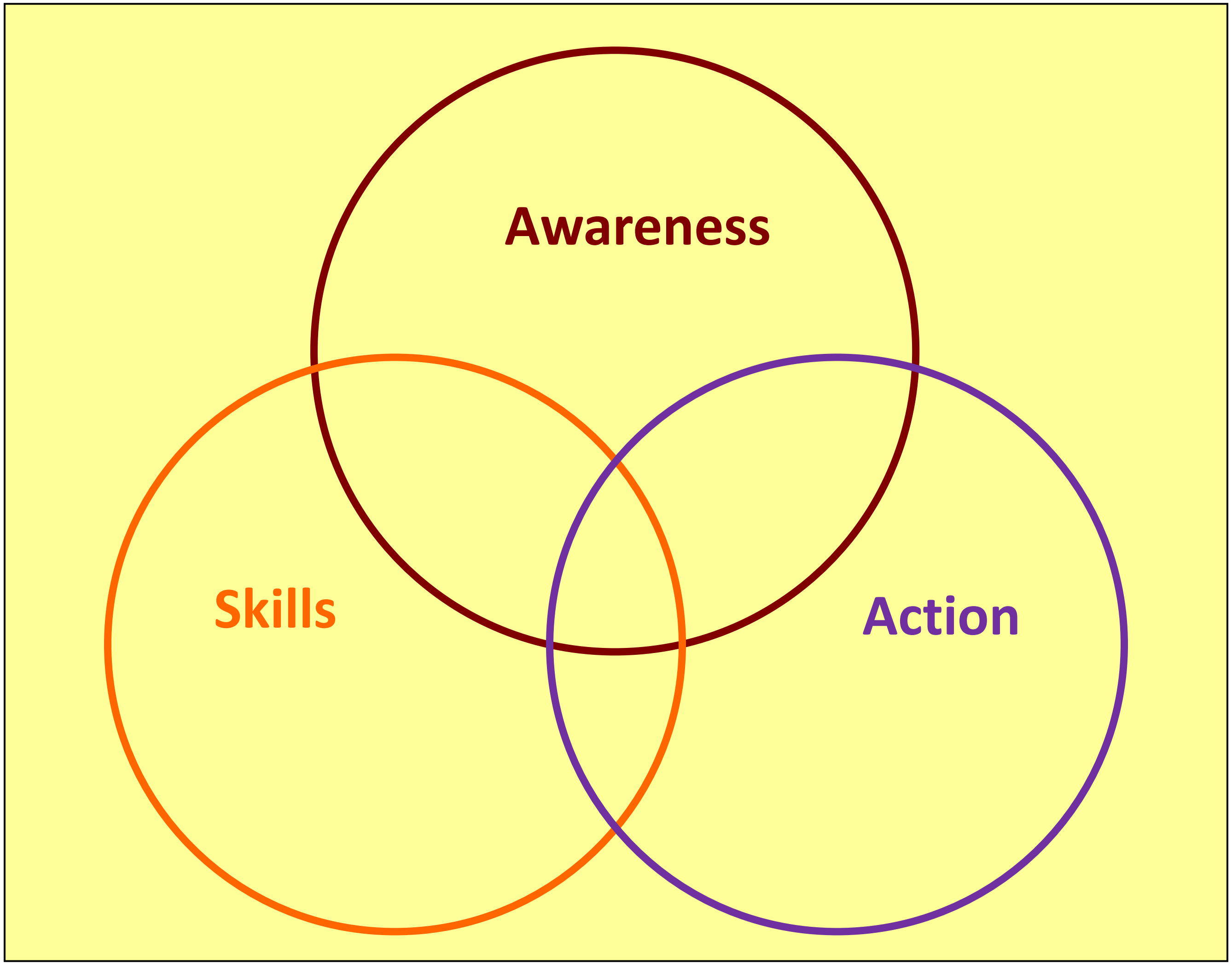








Factors To Consider For Implementing Sustainability



Questions?

Background Slides

12 Principles of Green Engineering[1]

1. **Inherent Rather Than Circumstantial**
   - *Designers need to strive to ensure that all materials and energy inputs and outputs are as inherently nonhazardous as possible.*
2. **Prevention Instead of Treatment**
   - *It is better to prevent waste than to treat or clean up waste after it is formed.*
3. **Design for Separation**
   - *Separation and purification operations should be designed to minimize energy consumption and materials use.*
4. **Maximize Efficiency**
   - *Products, processes, and systems should be designed to maximize mass, energy, space, and time efficiency.*
5. **Output-Pulled Versus Input-Pushed**
   - *Products, processes, and systems should be "output pulled" rather than "input pushed" through the use of energy and materials.*
6. **Conserve Complexity**
   - *Embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse, or beneficial disposition.*
7. **Durability Rather Than Immortality**
   - *Targeted durability, not immortality, should be a design goal.*
8. **Meet Need, Minimize Excess**
   - *Design for unnecessary capacity or capability (e.g., "one size fits all") solutions should be considered a design flaw.*
9. **Minimize Material Diversity**
   - *Material diversity in multi-component products should be minimized to promote disassembly and value retention.*
10. **Integrate Material and Energy Flows**
    - *Design of products, processes, and systems must include integration and interconnectivity with available energy and materials flows.*
11. **Design for Commercial "Afterlife"**
    - *Products, processes, and systems should be designed for performance in a commercial "afterlife."*
12. **Renewable Rather Than Depleting**
    - *Material and energy inputs should be renewable rather than depleting.*

- *"It is useful to view these principles as parameters in a complex and integrated system."*

[1] *Environmental Science & Technology, P. Anastas, and J. Zimmerman, March 1, 2003, p. 96A.*

NASA 2010 Strategic Sustainability Performance Plan

1.1 AGENCY POLICY STATEMENT

Worldwide, people have turned to NASA for inspiration throughout our history. We seek to drive advances in science, technology, and exploration to enhance knowledge, education, innovation, economic vitality, and stewardship of the Earth. NASA is an agency that leads by example and can continue to be a source of inspiration. We know that to keep pushing for the stars, to unravel the complex science that directs our planet's processes, we must proceed in a manner that preserves, enhances, and strengthens our ability to perform our mission indefinitely.

NASA's sustainability policy is to execute NASA's mission without compromising our planet's resources so that future generations can meet their needs. Sustainability also involves taking action now to provide a future where the environment and living conditions are protected and enhanced. In implementing sustainability practices, NASA manages risks to mission, risks to the environment, and risks to our communities. To this end, NASA seeks to use public funds efficiently and effectively, promote the health of the planet, and operate in a way that benefits our neighbors.

NASA 2010 Strategic Sustainability Performance Plan

1.1 AGENCY POLICY STATEMENT (continued)

To implement this policy, NASA commits to:

- increasing energy efficiency; 4
- increasing the use of renewable energy; 12
- measuring, reporting, and reducing NASA's direct and indirect greenhouse gas emissions;
- conserving and protecting water resources through efficiency, reuse, and storm-water management; 4
- eliminating waste, recycling, and preventing pollution; 2
- leveraging Agency acquisitions to foster markets for sustainable technologies and environmentally preferable materials, products, and services; 5
- designing, constructing, maintaining, and operating high performance sustainable buildings; 4 10 12
- strengthening the vitality & livability of the communities that surround NASA Centers & facilities;
- raising employee awareness and encouraging each individual in the NASA community to apply the concepts of sustainability to every aspect of their daily work to achieve these goals;
- maintaining compliance with all applicable Federal, state, local or territorial law and regulations related to energy security, a healthy environment, and environmentally-sound operations; and
- complying with internal NASA requirements and agreements with other entities.

http://www.nasa.gov/sustainability

Best Practices - Green Engineering Is Integrated Across All Aspects Of An Organization

- **Separate and distinct environmental programs are less effective than integrated programs.**
  - *However, stand-alone sustainability initiatives, with a smaller focus and champion(s), may show potential and help build initial support for subsequent comprehensive integration.*

- **Integration and application of Green Engineering should not be the responsibility of one person, one department, etc. but rather needs to go across levels, departments, and responsibilities.**
  - *If the concepts of sustainability – environmental, economic, and social equity – become a core organizational value, then every job becomes a green job with associated responsibilities.*

- **Environmental issues should be treated as systems issues and considered explicitly in decision-making.**

Best Practices – Green Engineering Is Promoted As A Powerful Tool

- **The efforts spent on Green Engineering efforts should be value-added for participants and organization, not just another paperwork exercise**
  - *Use of Green Engineering should lead to more options and better products, not a justification of the ways things are currently done.*
  - *Green engineering should be considered good engineering with measurable results including increased efficiency, cost reduction, more successful projects,, etc.*

NASA Green Engineering Short Course

1	Sustainability and Green Engineering Overview	• What is sustainability & green engineering? • Where do they overlap? • How are they different?
2	Green Engineering and Systems Thinking	• What are the fundamental concepts behind green engineering?
3	Environmental Issues and Impact Categories	• How do we start to understand the impact of our decisions and activities on humans and the environment?
4	Human Health Impacts	• How do we quantify how harmful a chemical or material is for humans, animals, ecosystems, etc.?

NASA Green Engineering Short Course

5	NASA Impacts Due to Environmental Regulations	• How do US and Foreign environmental regulations impact NASA missions? How can one consider these to avoid mission risks?
6	Design, Materials Selection, and Sustainable Manufacturing	• How can one explicitly consider environmental impacts when selecting a design, material, or manufacturing process?
7	Green Engineering Metrics 1	• How can we quickly qualitatively or quantitatively understand the impacts of our design decisions?
8	Green Engineering Metrics 2 – Life Cycle Assessment (LCA)	• How do we more accurately quantify and compare designs/systems to determine environmental impact?

OveNASA Green Engineering Short Course

9	**Green Engineering Software and Resources**	• **What resources and tools are available to explore and implement some of these concepts?**
10	**Integrating Green Engineering into NASA Design and Development**	• **How can we start to integrate these concepts within NASA's daily work?** • **Where are the leverage points within NASA processes?**

Risk Framework for Green Engineering

LCA Impact Indicator = Inventory Data x Characterization Factor

(Risk = Probability x Severity)

Environmental Impact Assessment

- Green engineering is basically a risk assessment of environmental issues.

Material released to or removed from the environment by human activity → **Material interacts with the environment** → **Environmental Effects:**
- Severity?
- Spatial extent?
- Time scale?

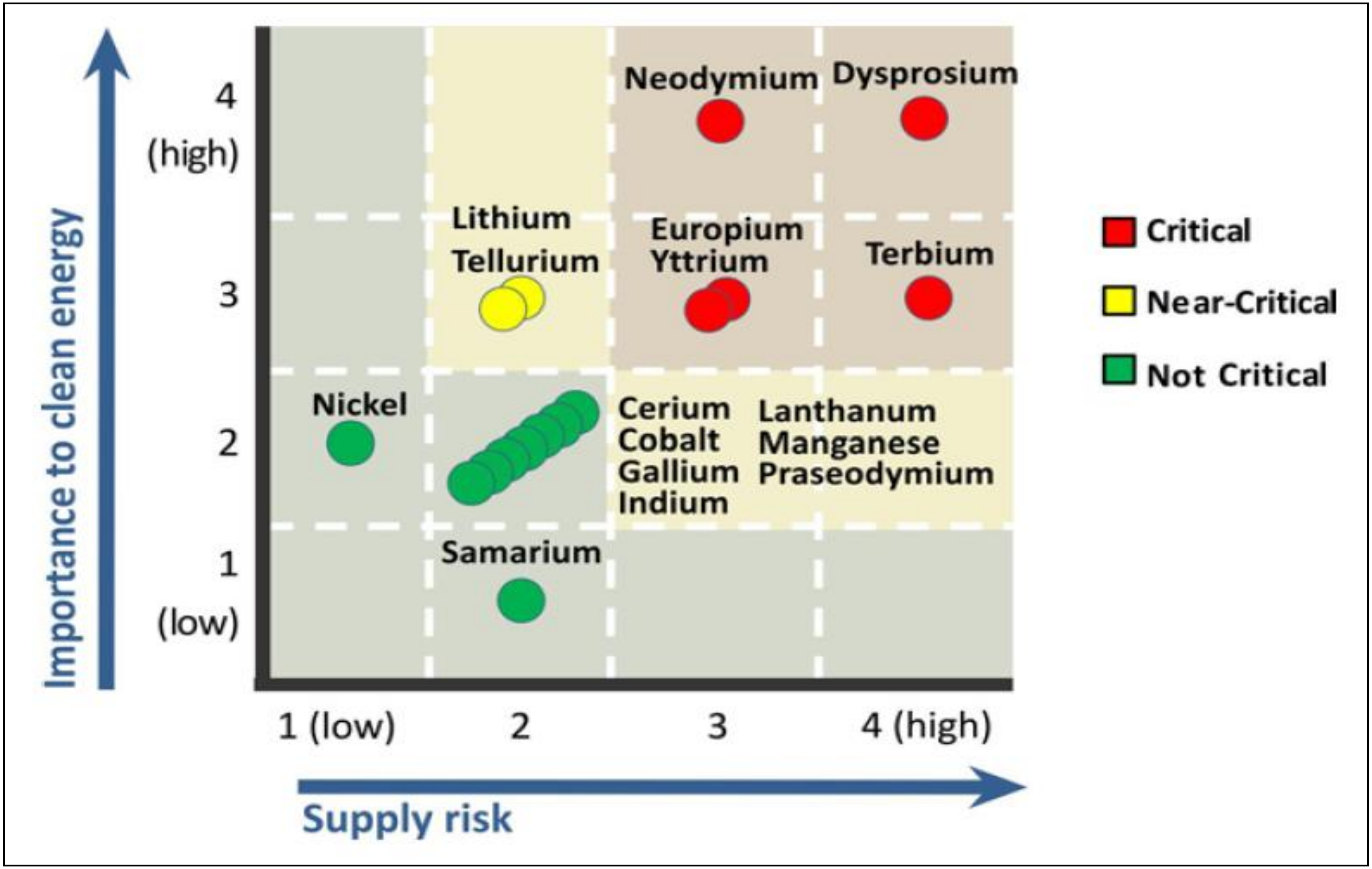
- Impact assessment (environmental risk) allows different environmental impacts to be **quantified** using the best available scientific data (characterization factors).

- Impact assessment allows different inputs/outputs to be put on the same quantitative scale with the same units. Impact indicators can be added together to get overall impact in a specific environmental category.

Impact Indicator = Inventory Data x Characterization Factor

(Risk = Probability x Severity)

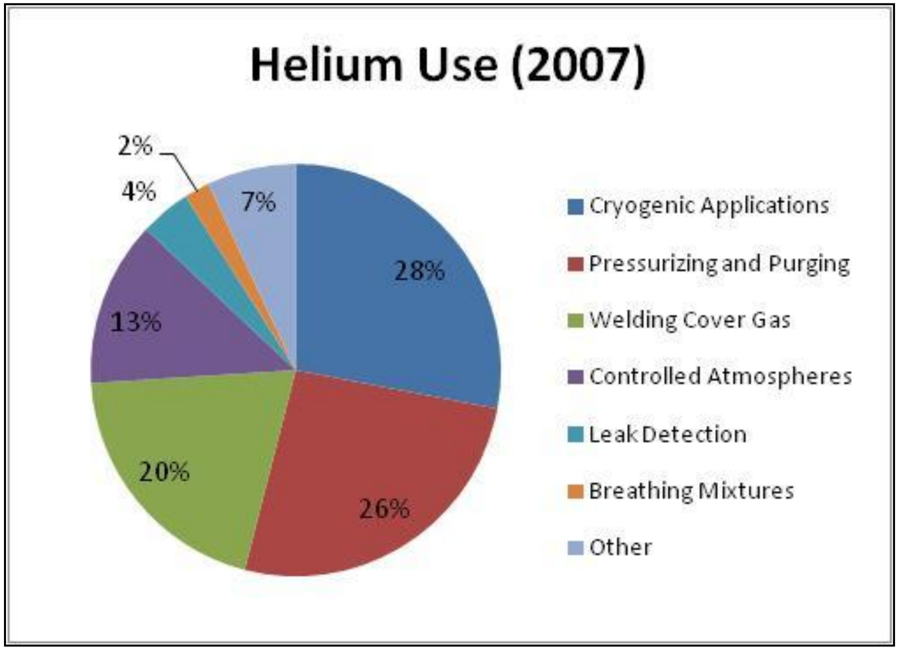
Rare Earth Metals Critical Risk Matrix



2011 DOE *Critical Materials Strategy*

Manufacturing Example – Helium Use

2007 US Helium Production and Consumption	Million Cubic Meters
Helium extracted from natural gas	80
Withdrawn from storage	58
Grade-A helium sales	138
Exports	68
US Consumption	70



- Essentially all consumed helium is not recycled and is therefore lost.
- In most cases, the recapture of helium is not currently feasible due to process constraints or economics.

NASA, Helium Availability, Tom Elam, Kennedy Space Center

VirginiaTech
Invent the Future

Manufacturing Example – Helium Use

- Currently , NASA receives helium from thru commercial suppliers who have agreements to obtain their crude (unrefined) helium from the Bureau of Land Management (BLM) federal helium reserve.

- **Helium Privatization Act of 1996**
  - *Requires the BLM to sell off most of the Federal Helium Reserve by 2015.*
  - *Once the BLM Reserve is depleted (current estimates are 2018 - 2020), NASA and others will be obligated to obtain helium from sources on the open market, which increasing are foreign owned.*

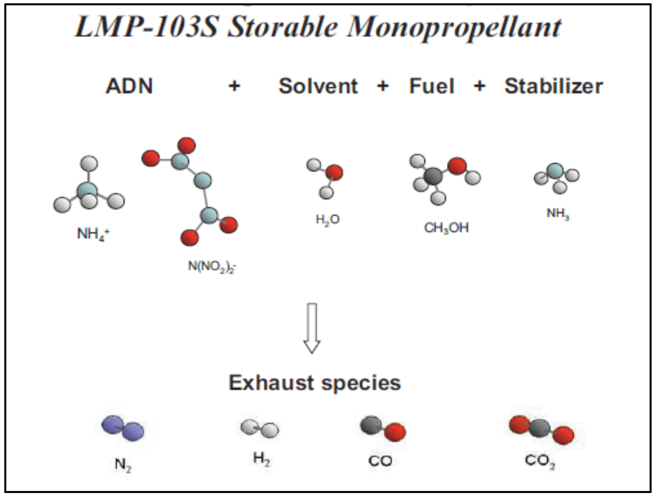
- Long term helium outlook is expected to get increasingly tight as the US federal helium reserve is drawn down and usage is expected to continue to increase due to economic and technological growth

Case Study: Prototype Research Instruments & Space Mission Technology Advancement (PRISMA)

- The PRISMA mission launched in June 2010 to test carries a variety of low cost technologies from across Europe.

- The larger Prisma satellite featured two experimental thrusters burning hydrazine as a baseline and High Performance Green Propellant (HPGP) based on ammonium dinitramide - LMP103 (ADN)

- "This ***non-toxic*** fuel is more ***environmentally-friendly*** and efficient than hydrazine propellant used on most satellites. …..It's a fuel that actually can be flown on regular aircraft…… It has a ***much more benign composition*** than hydrazine."



http://www.spaceflightnow.com/news/n1006/07prisma/

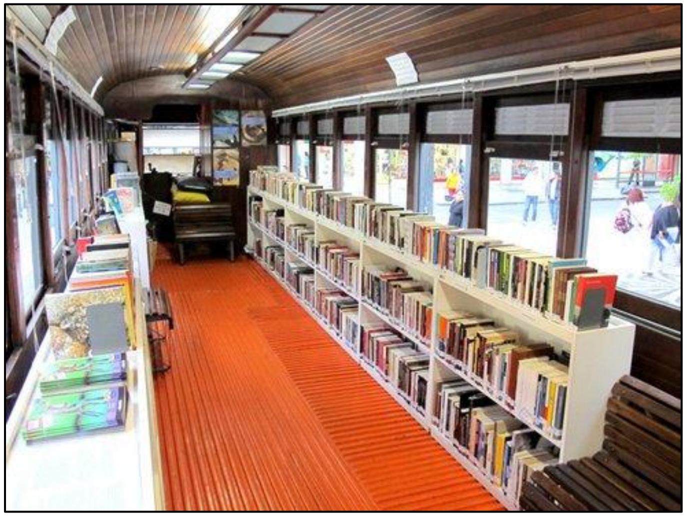
Dr. C. Johnson, GSFC Deputy Director for Science and Technology, Environmental Life Cycle Criteria for Making Decisions about Green vs. Toxic Propellant Selection, APPEL Green Engineering Course, March 21, 2012.

Case Study: Prototype Research Instruments & Space Mission technology Advancement (PRISMA)

Handling and Operations Comparison:

	HPGP	Hydrazine
Protective Gear	No SCAPE suits	SCAPE suits required
Loading Time	7 days	14 days
Loading Labor	2 specialists and 1 part-time technician	5 mission specialists and 20 support specialists
Waste	¼ gallon of propellant and ¾ gal of isopropyl alcohol/de-ionized water Disposal of these wastes was provided at no charge because of the non-toxic classification.	8 gallons of hydrazine, 105 gal of contaminated de-ionized water, and 18 gallons of isopropyl alcohol waste. Hazardous waste procedures had to be followed.
Cost Estimate	~$215,000	~$653,000

Reuse



http://www.treehugger.com/culture/recycled-train-wagon-transformed-street-library-curitiba.html